Charge Injection and Discharging of Si Nanocrystals and Arrays by Atomic Force Microscopy

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Charge injection and storage in dense arrays of silicon nanocrystals in SiO_2 is a critical aspect of the performance of potential nanocrystal flash memory structures. The ultimate goal for this class of devices is few- or single-electron storage in a small number of nanocrystal elements. We have recently demonstrated state-of-the-art Si nanocrystal non-volatile memory devices. In order to understand and characterize Si nanocrystals for non-volatile memory applications, it is also important to characterize individual or small numbers of nanocrystals.

Conducting-tip atomic-force microscopy (AFM) has been used to probe single Si nanocrystals on an insulating substrate. The nanocrystals are produced by aerosol techniques by which narrow size distributions can be formed with an average size of less than 2 nm. We have also performed charging experiments on Si nanocrystal ensembles formed by ion implantation and annealing of SiO_2 films.

Using a conducting AFM tip, charge was injected directly into the nanocrystals. The trapped charge produces an electrostatic force component that changes the response of the AFM tip, causing a change in the apparent height of the nanocrystal. Constant-force-gradient contours have been calculated that agree well with measured profiles, and we can determine the amount and location of the injected charge as well as some details of the discharge mechanism. Modeling indicates a discharge mechanism consistent with tunneling through a field-lowered barrier.

We will also discuss the next steps in this project, which include tests for radiation hardness and the use of artificial tunnel barrier heterostructures with the potential for large speed enhancements for read/write of nanocrystal memory elements.